Some provisions of calculations of hydraulic structures according to Russian norms and American standards

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Abstract. Ensuring the safety of hydraulic structures should be carried out, including calculations of the stress-strain state of the system "structure–base" by the method of limit States. A summary system of reliability coefficients, a combination of loads and operating conditions for different design cases is presented. Considered the stability condition of the concrete dam on the shift on the substrate. A comparison of the values of the generalized dam stability coefficients (reserve) according to Russian norms and American standards is performed. It is shown that when comparing the numerical values of the strength and stability coefficients regulated in the Russian norms and American standards, it is necessary to take into account the methods of determining the strength characteristics of materials, the practice of taking into account loads and effects, as well as the methods of computational studies of the stress-strain state of structures and their bases.

1 Introduction

A variety of hydraulic structures for functional purposes and industry affiliation creates some difficulties in solving the problems of their own safety. Given the importance of hydraulic structures for various sectors of the economy, which are part of power plants, water transport systems, water supply systems and irrigation, special attention should be paid to own the security of such facilities, most of which were built 50-60 years ago.

Ensuring the safety of hydraulic structures should be carried out, including calculations of hydraulic, filtration and temperature regimes, as well as the stress-strain state of the system "structure – base", based on the results of calculations by the method of limit States.

2 Methods

For the limit state is taken such that the hydraulic structure (design) or its base ceases to meet the specified operational requirements. This means that:

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- the magnitude of the forces and stresses developing in the structure (structure) or the base shall not exceed the carrying capacity of the structure (limit States of the first group - for unsuitability for operation);
- the value of deformations (displacements) of the structure shall not exceed the permissible for the normal operation of the structure (limit States of the second group - for unsuitability for normal operation).

The requirements of strength calculation are reduced to ensure that the values of forces, stresses, strains and displacements arising in the structure from the loads do not exceed the limits determined in accordance with the design standards.

The first limit state of the structure (strength or stability) occurs when the calculated generalized load f reaches the calculated value of the generalized carrying capacity of the structure (base). The calculations of the first group of limit States include the calculations of the total strength and stability of the system "structure-base"; the filtration strength of the base and the structure, on which the strength of the structure as a whole depends.

The second limit state assumes calculations of local, including filtration, strength of the base and structure; cracks and construction seams opening; strength of structural elements of the structure.

3 Results

In the calculations of hydraulic constructions, structures and grounds to comply with a condition to ensure that occurrence of the limit state, i.e. the assessment of onset of first limiting condition produced by the condition:

$$\gamma_n \, \gamma_{lc} \, F\,(\gamma_f) \;\leq\; \gamma_c \, R \qquad\qquad (1)$$

In formula (1):

γ_n - factor of reliability on responsibility (purpose) of the construction; γ_{lc} - coefficient of combination of loads; γ_c - coefficient of working conditions accepted according to [1, 2];

F, R - respectively, the calculated values of the generalized force effect, taking into account the reliability factor for the load γ_f and the generalized bearing capacity of the structure.

Load $F = F\,(\gamma_f) = \gamma_f \, F_{norm}$ is determined by multiplying the standard load value of F_{norm} by the corresponding load reliability factor γ_f: $F = F\,(\gamma_f) = \gamma_f \, F_{norm}$.

Normative values of loads F_{norm} should be determined by the normative documents for the design of certain types of hydraulic structures, their structures and bases.

The value of the load reliability factor γ_f, when calculating the limit States of the first group should be taken in accordance with [2] and table 1.

Table 1. The coefficient of reliability for the load.

Loads and impacts	γ_f
Water pressure directly on the surface of the structure and the base; power effect of filtering water; wave pressure; pore pressure	1,00
Own weight of the structure (without the weight of the soil)	1,05 (0,95)
The weight of the soil (vertical pressure from weight of soil)	1,10 (0,90)
The lateral pressure of soil	1,20 (0,80)
Sediment pressure	1,20
Ice load	1,10
Loads from lifting and handling vehicles	1,20
Seismic impact	1,00

The value of the coefficient of working conditions γ_c, taking into account the type of hydraulic structures and the base, features of the design and the approximation of the design schemes, for example, for concrete dams is taken according to [2] and table 2.

Table 2. The values of coefficient of operating conditions.

Types of calculations of dams and factors causing the introduction of coefficients of working conditions	γ_c
Calculations of stability of concrete (reinforced concrete) dams on semi-basement and non-rock foundations	1,00
Calculations of stability of concrete dams (gravity and buttress) on rock foundations for shear surfaces passing through: (a) cracks in the base mass (b) the contact concrete-rock and in the mountains the Foundation of the partly cracked, partly for the monolith	1,00 0,95
Calculations of the stability of the coast the abutments arch dams	0,75

The value of the reliability coefficient for the responsibility (class) of the structure γn, taking into account the degree of responsibility, the capital of the structure and the significance of the possible consequences in the event of a limit state (accident, flooding), is taken into account when calculating the limit States according to [2] and table 3.

Table 3. The value of the reliability coefficient on the responsibility (class) structures.

Limit States of group 1				Limit state of 2-nd group
Construction class				
I	II	III	IV	
1,25	1.20	1,15	1,10	1,00

The value of the load combination factor γ_{lc} in the calculations for the first group of limit states is taken according to [2] and table 4, and in the calculations for the second group of limit states - equal to 1.00.

Table 4. Load combination ratio values.

Load combination				
The main combination (Usual)		Special combination (Unusual)		
the period of normal operation	the period of construction and repair	including seismic at the level of the project earthquake (OBE) annual probability of 0.01 and less	when a special load, in addition to seismic annual probability of 0.001 and less	at seismic load of the maximum calculated earthquake level MCE
1,00	0,95	0,95	0,90	0,85

In foreign practice, the design earthquake is indicated by OBE (Operating basic earthquake) and the maximum credible earthquake – MCE (Maximum credible earthquake).

The main combination of loads and impacts during normal operation usually includes short-term loads with an annual probability of more than 0.01. And seismic impacts should be carried out by [3].

Thus for dams of I and II classes calculation is carried out on two levels of seismic influences: OBE and MCE, and for dams of III and IV classes - only on OBE.

A summary system of all the above coefficients for different calculated cases is given in table 5.

Table 5. Values of reliability factors, combination of loads and working conditions.

Estimated cases	Limiting state							
	1 group						2-nd group	
	γ_n				γ_{lc}	γ_c	γ_n	γ_{lc}
	I	II	III	IV				
Building-repair					0,95			
Usual	1,25	1,20	1,15	1,10	1,00	1,00 (0,95)	1,00	1,00
Unusual					0,85…0,95			

Under the influence of external forces, a hydraulic structure, for example, a dam, must be stationary (not to move and not to tip over), to be stable. Performing stability calculations, evaluate the ratio of holding and shear forces. It is required that the dam has some margin of stability, measured by the factor of stability.

The horizontal forces acting on the dam: the horizontal component of water pressure on the upstream and downstream faces of the dam; the pressure of sediments from the upper tail; the pressure of the ice and waves. Vertical forces acting on the dam: own weight of the dam body; vertical component of water pressure; weighing and filtration pressure on the bottom of the dam.

All the forces acting on the hydraulic structure, after the summation, can be represented by two components: horizontal T and vertical G. The two main types of equilibrium: the structure will be shifted by the force T on the base, or the structure will be tilted by the force T and the counter-pressure force W around the lower edge of the dam.

Next, we consider only the stability of the concrete dam to shift on the surface of the base. Calculation of stability of gravitational dams on shift is carried out according to [4]. The resistance of the structure to the shear force T is created by the force proportional to the vertical component G and equal to $f*G$ (excluding the coupling force), where f is the shear resistance parameter equal to 0.2...0.8, depending on the properties of the base and the dam material. The structure will be stable against shear if $T \leq f*G$.

Calculation of stability of the dam on shift is carried out by calculation of factor of a stock of $K_Z = (G \, \mathrm{tg}\varphi + C \, b) / T$, where b is the width of the sole of the dam, comparing it then with admissible factor of a stock. The calculated values of the safety factor should not be less than acceptable, but also a significant excess of them is undesirable.

Thus, the criteria of reliability (strength and stability) and their numerical values for hydraulic structures in Russia are regulated by national standards, codes of practice and other normative documents approved at the state level.

The most common in the world practice of designing hydraulic structures received the standards of American organizations:

• US Army Corps of Engineers – 1995 (USACE). Provides civil and military services in the U.S. and abroad, including dams, canals, and flood protection. The mission of the USACE planning, design, construction and operation of waterworks and dams, the implementation of other projects in the field of civil construction, including control of the maximum runoff and flood protection, dredging for navigation, environmental regulation and ecosystem restoration.

• US Bureau of Reclamation (USBR). Controls the management of water resources. Coordinates irrigation and dam construction at the national level. The official mission of reclamation is "to manage, develop and protect water and related resources in an environmentally and economically sound manner in the interests of American society".

• Federal Energy Regulatory Commission (FERC). Regulates the transmission and wholesale of electricity and natural gas in the system of trade between the States.

Let's write down the condition (1), which is true for both Russian and American standards:

$$F\,(\gamma_f) \leq \gamma_c\,R\,/\,(\gamma_n\gamma_{lc})\quad \text{or}\quad F\,(\gamma_f)\ \leq\ R\,/\,\gamma_{st} \tag{2}$$

where: γ_{st} – generalized construction stability factor (the value showing the ability of the structure to withstand the load applied to it above the design), $\gamma_{st} = (\gamma_n\,\gamma_{lc})\,/\,\gamma_c$.

In calculations of stability of concrete dams (gravitational and buttress) as constructions of the I class on the rock bases for the surfaces of the shift passing on cracks in the massif of the basis or contact concrete-rock and in the massif of the basis partially on cracks, partially on the monolith, numerical values of the generalized coefficient of stability of the dam γ_{st} for various settlement cases of combination of loadings and influences on the first group of limit states can be accepted as in table 6.

Table 6. Values of the generalized stability coefficient γ_{st} Russian standards (for dams of I class).

The combination of pressures and impacts (design cases)		γ_{st}	
		on cracks in the massif of the base	on contact concrete-rock and in the array of the base
Usual		1,25	1,32
Unusual (Special) without seismic effects		1,13	1,18
Unusual (Special) with seismic effects	OBE	1,19	1,25
	MCE	1,06	1,12
Building-repair		1,19	1,25

Comparison of the values of the generalized stability factors of γ_{st} according to Russian norms and American standards [5, 6] is given in table 7.

Table 7. A comparison of the values of generalized coefficient of stability of the dam.

The combination of pressures and impacts		Stability factor						
USACE – 1995, USBR, FERC– 2002 Load Condition	Russian codes of practice	USACE - 1995	USBR		FERC - 2002		Russian codes of practice	
		Minimum Sliding factor of safety FS	Shift by		When using shear strength		Shift by	
			crack shear	con-tact	peak strength	residual	crack shear	the contact concrete-rock
Usual	Usual	2,00	4,00	3,00	3,00	1,50	1,56	1,65
Unusual	without seismic	1,70	2,70	2,00	2,00	1,30	1,41	1,48
	OBE						1,49	1,56
	Building-repair						1,49	1,56
Extreme	with PMF	1,30	1,30	1,00	1,30	1,00	1,41	1,48
	MCE						1,33	1,40
	Building-repair with OBE						-	-
Post-seismic	-	1,30	-	-	2,00	1,10	-	-

PMF (probable maximum flood) - maximum probable flood. Values of shear stability coefficients for normative values of shear resistance parameters.

4 Discussion

A significant difference in the values of the generalized stability coefficients according to Russian norms and American standards with the main combination of loads is explained by the fact that the normative documents of American organizations use the peak shear strength, while the Russian norms regulate the use of residual strength (due to differences in the procedure for determining the shear resistance parameters).

In addition, in American standards there is a calculated post-seismic case (post-seismic), which is absent in Russian regulations. The stability calculations for this calculation case use the residual values of the tangent of the internal friction angle $tg\varphi$ and the coupling C in the Coulomb-Mohr failure criteria.

When comparing the numerical values of the strength and stability coefficients, regulated in the Russian norms and American standards, at first glance shows a more bold and risky approach to the justification of the reliability of facilities in Russia. But it is necessary to take into account the methods of determining the strength characteristics of materials, the practice of accounting for loads and impacts, as well as take into account the methods of computational studies of the stress-strain state of structures (structures) and their bases.

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